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mb:Ms Screening Revisited for Large Events

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$m_b:M_s$ Screening Revisited for Large Events

by Sean R. Ford and William R. Walter

Abstract Event screening of large magnitude events ($M_W \sim > 5$) based on $m_b:M_s$ is revisited to account for the effect of the source corner-frequency relative to the fixed-frequencies of the long-period M_s and short-period m_b . For large events this source effect increases the slope of $m_b:M_s$ relative to the 1:1 value expected for small events. The effect is demonstrated in the large earthquake $m_b:M_s$ population and its behavior is transferred to the more limited explosion population to create a more conservative screening criteria. The change in criteria ensures large explosions are not inadvertently screened out by $m_b:M_s$ while not appreciably decreasing the number of screened earthquakes. This change also makes the variance of the earthquake and explosion populations more equal, which is of utility in statistical analysis. A slight trend in the explosion population and a case study of two large US underground nuclear tests provide support for adopting a more conservative approach.

Introduction

The ratio of the body-wave magnitude (m_b) of an event to its surface-wave magnitude (M_s) is a function of two effects: (1) the relative excitation between surface and body waves; and (2) the source corner-frequency relative to the period at which m_b (~ 1 s)

and M_S (~ 20 s) are measured. Analytical (Stevens and Day, 1985) and empirical (Marshall and Basham, 1972) studies of the magnitude ratio $m_b:M_S$ support a separation of earthquake and explosion populations based on the first effect, and current event screening criteria takes advantage of this very effectively (Selby et al., 2012). However, as Hanks and Boore (1983) point out, practical magnitude measurement should also take into account the second effect, since the ratio of magnitudes measured at fixed-frequencies change as a function of event size due to the change in corner-frequency. In this study we show that the fixed-frequency effect explains an observed deviation in $m_b:M_S$ slope at large magnitude for the earthquake population. Due to the small explosion population at large magnitude this effect cannot be rejected and a conservative event screening approach could allow for its incorporation.

Data

The earthquake magnitudes used here are from a similar dataset to Selby et al. (2012), namely the IDC *REB* events for the first decade of the millennium (2000-2009). Excluding events with depths greater than 10 km and those with only one M_S observation leaves 7875 events in the population. While it is assumed that the population of *REB* events consists overwhelmingly of earthquakes, no attempt has been made to identify other types of events, such as quarrying explosions or mine collapses.

The explosion magnitudes used here are from the compilation presented in Selby et al. (2012). We refer the interested reader to their paper for more information on the dataset.

Analysis

Figure 1a shows the earthquake and explosion $m_b:M_S$ population density. The separation between the two populations provides a discrimination capability that has been employed for more than a half-century of nuclear explosion monitoring (Douglas, 2007). Stevens and Day (1985) presented evidence that the explosion $m_b:M_S$ slope should be unity ($M_S = \beta m_b + \alpha$, where $\beta=1$), and there is consensus support for this slope from the Waveform Expert Group of Working Group B of the Comprehensive Test-ban Treaty Organization as described in Selby et al. (2012). In order to analyze trends in the populations the data are rotated under the assumption of unity $m_b:M_S$ and the mean and standard deviation of moving 0.3-unit bins are calculated (Figure 1b). The trend evident in the earthquake population is evidence for a non-unity slope of $m_b:M_S$ for earthquakes. This is cause for concern since under the adopted linear discriminant analysis approach of the current event screening criteria there is an assumption of similar slopes for the earthquake and explosion populations. In the next section we provide a basis for this departure from unity slope and offer an improvement to the screening criteria to account for it.

Proposed Change to the Revision to the Standard $m_b:M_S$ Screening Line

The recorded spectrum of an event is formed from the product of the instrument response and the source spectrum. Hanks and Boore (1984) show that when the instrument response is of the Wood-Anderson type and the earthquake source spectrum is the omega-squared model of Brune (1970) then for large events where the source corner frequency is much less than the frequency at which local magnitude, M_L , is measured, the ratio of moment magnitude, M_W , to M_L is approximately three. For nearly all but the largest earthquakes (e.g. $M_S > \sim 7.5$) $M_W \approx M_S$ (e.g. Hanks and Kanamori, 1979; Stevens and McLaughlin, 2001; and Patton, 2001). The IDC m_b is measured over a 0.8 to 4.5 Hz band and Granville et al. (2005) shows the IDC m_b response is similar to the Wood-Anderson response on which M_L is based. Therefore, $M_S \sim 3m_b$ for large events, but the question becomes the definition of large event. For the answer we turn to the empirical analysis from the previous section.

In order to modify the screening line for large events we use two different techniques that result in very similar answers. First we fit a slope of 3 to the largest earthquake events and then map that slope to the explosion population. Second we employ a slope=3 at the point where the explosion mean seems to steepen around m_b 6. In both cases the large event screening line is then set to be the same distance from the explosion line with slope=3 at large m_b . The offset from the mean explosion line at large magnitudes is made the same as the offset for small magnitudes set by the revised screening line discussed in Selby et al. (2012). This criteria results in a transfer of unity slope to a

screening line with slope of three at m_b 5.37, so that the proposed change to the revised screening line is

$$M_s = \begin{cases} m_b - 0.64 & m_b \leq 5.37 \\ 3 m_b - 11.38 & m_b > 5.37 \end{cases} \quad (1)$$

Impact on Revised Event Screening

Figure 3 compares the proposed change to the screening criteria (Figure 3b) with the revised screening criteria (Figure 3a) presented in Selby et al. (2012). After the additional IDC land/sea screening criteria, only four more 2000-2009 *REB* events are not screened out, which represents less than 0.07% of the population – a small change to the operational burden. These four events are listed in Table 1, where one is located very deep by the US Geological Survey making it an unlikely explosion.

The Selby et al. (2012) revised screening line is such that the probability of a screened explosion is approximately 0.1% for a normal distribution of explosions derived from the historical population. The proposed change to the revised screening line given in eq (1) would result in an even lower probability of a screened explosion of 0.05%, so that the trade-off with an increased operation burden of 0.07% more unscreened events is a factor of two increase in confidence that an explosion isn't screened.

Figure 2 offers a hint of change in $m_b:M_s$ behavior of explosions near $m_b=6$, but due to lack of data it is difficult to draw as strong a conclusion as for the earthquake population. We investigate the possible presence of the slope change in the explosion population through the analysis of the regional recordings of two large US underground nuclear tests, HANDLEY and PIPKIN (Table 2).

The P -waves observed at the Lawrence Livermore Network station in Elko, Nevada (ELK, now an IMS auxiliary station) are shown in Figure 4. Note the smaller explosion PIPKIN P waveforms contain higher frequency energy than HANDLEY as clearly visible in the time domain and spectral results. The explosions are located only a few km apart and are recorded on the same instruments, so the observed differences reflect source differences. The apparent P -wave corner frequency for HANDLEY is about 0.6 Hz, whereas for PIPKIN it appears to be greater than 1 Hz. It is this source difference relative to the IDC m_b band of 0.8-4.5 Hz, which is peaked at the high-end in displacement (Granville et al., 2005, Figure 4b), that leads to a smaller m_b-M_s difference for HANDLEY compared to PIPKIN, consistent with the larger $m_b:M_s$ slope for large explosions. Finally we note that standard P -wave explosion models such as Mueller-Murphy (1971) also predict that the explosion corner frequency will drop below 0.8 Hz for very large explosions (e.g., > 1 Mt in tuff).

Discussion and Conclusions

One lesson from the $m_b:M_S$ analysis of the DPRK events is that empirical approaches to create screening decision lines can result in problems for event screening at the extremes of the explosion $m_b:M_S$ population. Since $m_b:M_S$ is based on fixed-frequency measurements, the behavior of these magnitudes at large magnitudes and small corner-frequencies must be incorporated to the screening criteria.

There are three reasons to adopt the more conservative $m_b:M_S$ screening criteria described here; 1) magnitudes based on narrow-band measurements will saturate such as m_b grows large, 2) the increased conservancy of the new line at large magnitude ensures that a very large explosion is not inadvertently screened out without an appreciable impact on the number of screened events, and 3) a magnitude-dependent approach makes the earthquake population variance more equal to the explosion population variance, a requirement for statistical processing such as linear and multivariate discriminant analysis that is of interest to State Parties to the CTBT and is an active area of research (Anderson et al., 2007).

Data and Resources

Magnitudes can be accessed from the International Seismological Centre (?)

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List of Figure Captions

Figure 1. a) $m_b:M_S$ of earthquake (blue, source: IDC *REB* 2000-2009) and explosion (red, source: Selby et al., 2012) event density with mean (μ , circle) and standard deviation (σ , bar) from 0.3-width bins of b) the transformed data.

Figure 2. Running $m_b:M_S$ means of earthquake (blue circles) and explosion (red circles) population as derived in Figure 1 along with explosions (gray crosses from Selby et al. (2012)). $M_S \propto m_b$ and $M_S \propto 3m_b$ fits to the small and large magnitude earthquake means (light blue lines), respectively, are plotted and the change in slope is transferred to the explosion population (dashed light red line) to form the proposal for a change (dashed black line) to the revised screening line (black line).

Figure 3. Comparison of screening criteria. a) Revised screening criteria presented in Selby et al. (2012) and b) proposed change to that revised screening criteria. Four more events (0.07%) are not screened out with the proposed change.

Figure 4. Regional analysis of US nuclear explosions, HANDLEY (red) and PIPKIN (blue). a) Vertical velocity recorded at Elko, Nevada (ELK $\Delta = 400$ km). The P_n portion of the P -wave (0.25 s duration) is magnified and the smaller explosion PIPKIN signals are multiplied by a factor of 10. Note PIPKIN contains higher frequency signals than HANDLEY. b) Displacement spectra of the P -wavetrain shown in a). Note the lower apparent corner frequency near 0.6 Hz for HANDLEY compared to something near 1 Hz for PIPKIN. When

231 the IDC m_b is measured in the 0.8 to 4.5 Hz band (shown in grey) it leads to saturation of m_b
232 for very large explosions and a steepening of the $m_b:M_s$ slope.

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Tables

Table 1. Unscreened events due to change to revised screening

Date [MM/DD/YY]	IDC <i>REB</i>						USGS <i>PDE</i>		
	Latitude	Longitude	Depth [km]	m_b	M_S		Depth [km]	m_b	M_S
03/28/09	-2.9076	139.5644	0	5.7	5.2	93	5.8	---	
01/07/08	-0.8137	134.0235	0	5.6	5.3	12	6.0	5.6	
04/22/06	61.209	167.3674	0	5.5	5.0	12	5.8	5.1	
08/17/06	46.5719	141.9290	0	5.6	5.1	14	6.0	5.2	

Table 2. Case study event information (Pahute Mesa explosions from Springer et al., 2002)

Name	Date [MM/DD/YY]	Time [hh:mm:ss]	Latitude	Longitude	Depth [m]	m_b^*	M_S^*
HANDLEY	03/26/70	19:00:00	37.300	-116.535	1209	6.37	5.27
PIPKIN	10/8/69	14:30:00	37.257	-116.442	624	5.53	4.20

* From Selby et al. (2012)

Figures

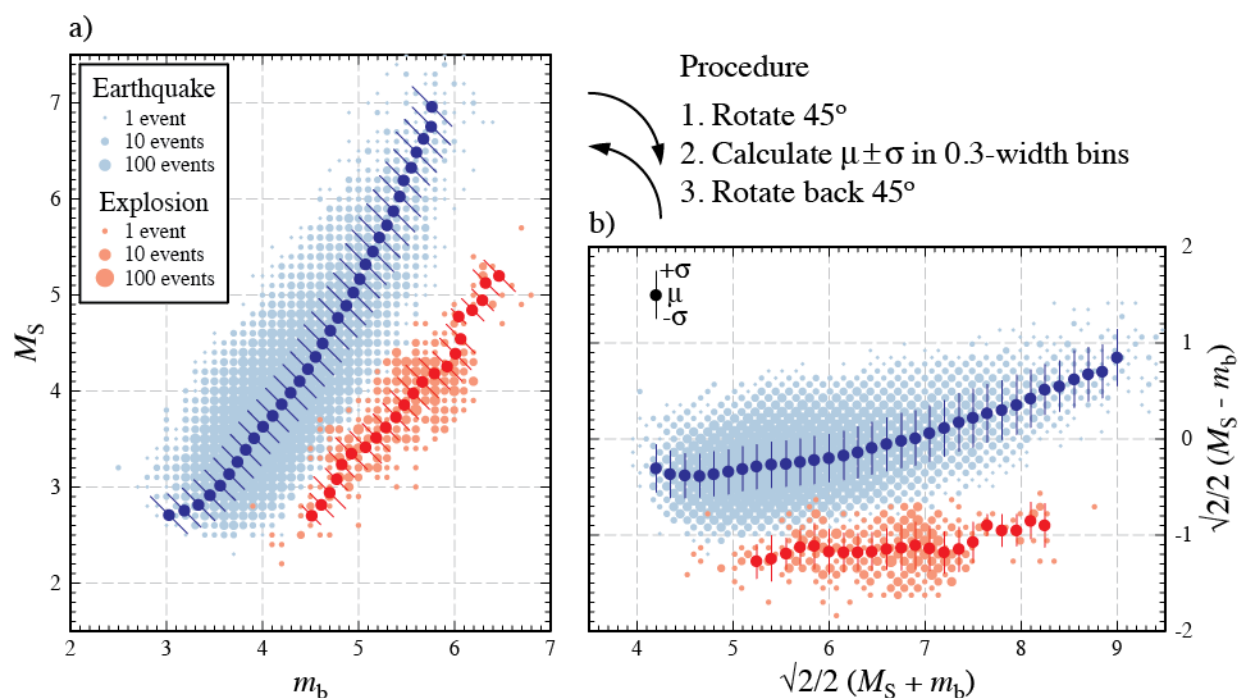


Figure 1 (mbmsdensity). a) $m_b:M_S$ of earthquake (blue, source: IDC *REB* 2000-2009) and explosion (red, source: Selby et al., 2012) event density with mean (μ , circle) and standard deviation (σ , bar) from 0.3-width bins of b) the transformed data.

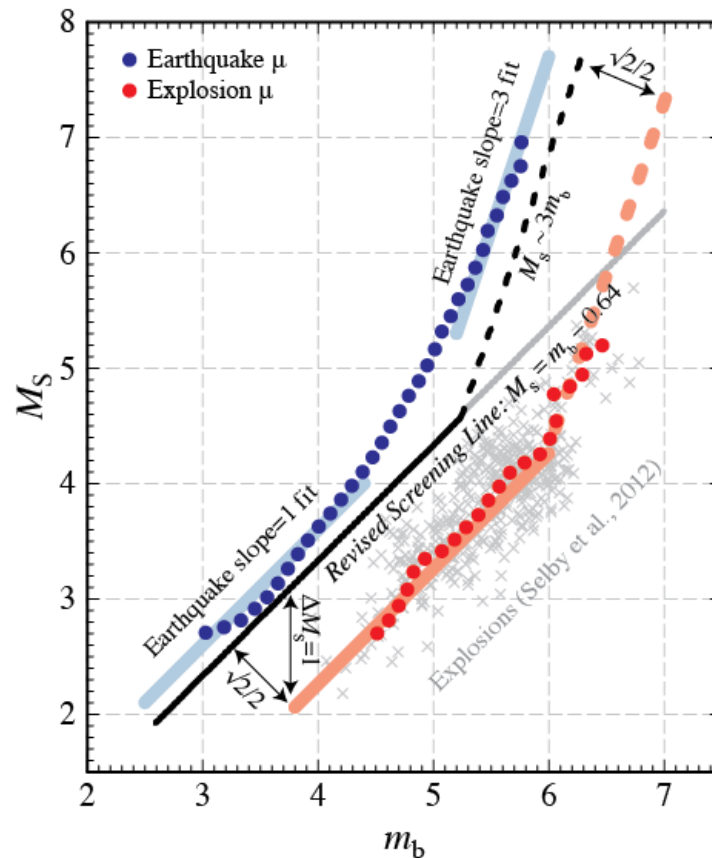


Figure 2 (discrim). Running $m_b:M_S$ means of earthquake (blue circles) and explosion (red circles) population as derived in Figure 1 along with explosions (gray crosses from Selby et al. (2012)). $M_S \propto m_b$ and $M_S \propto 3m_b$ fits to the small and large magnitude earthquake means (light blue lines), respectively, are plotted and the change in slope is transferred to the explosion population (dashed light red line) to form the proposal for a change (dashed black line) to the revised screening line (black line).

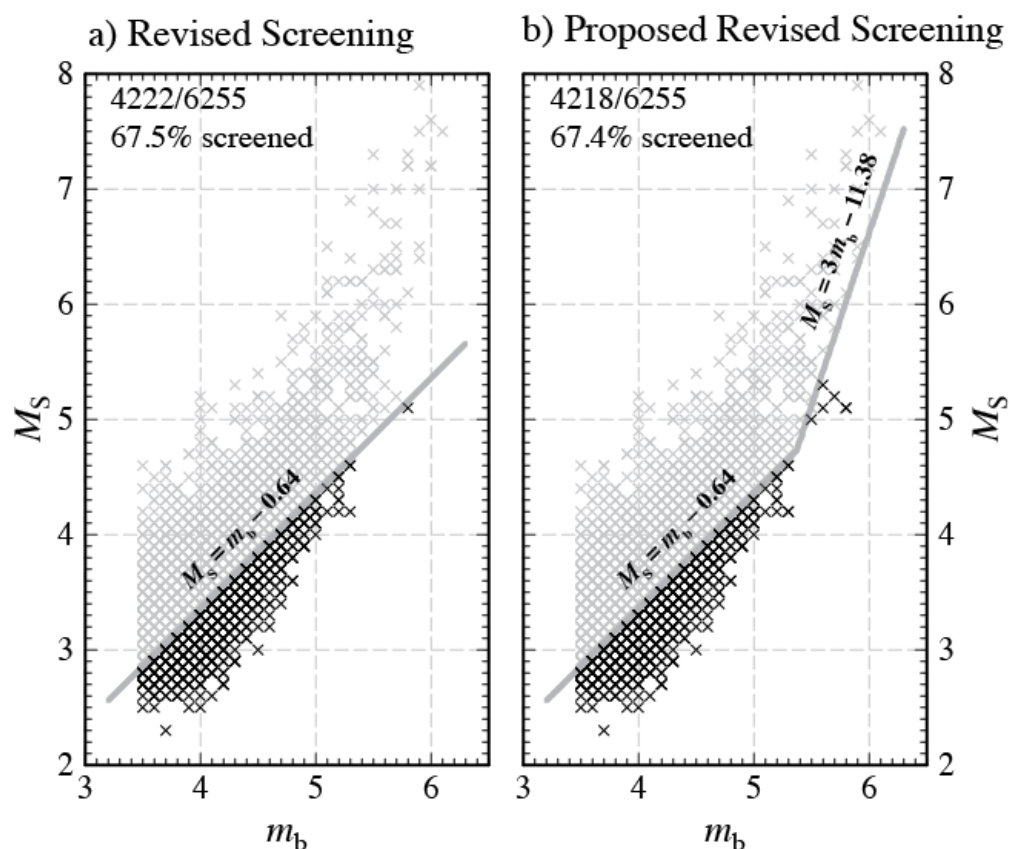


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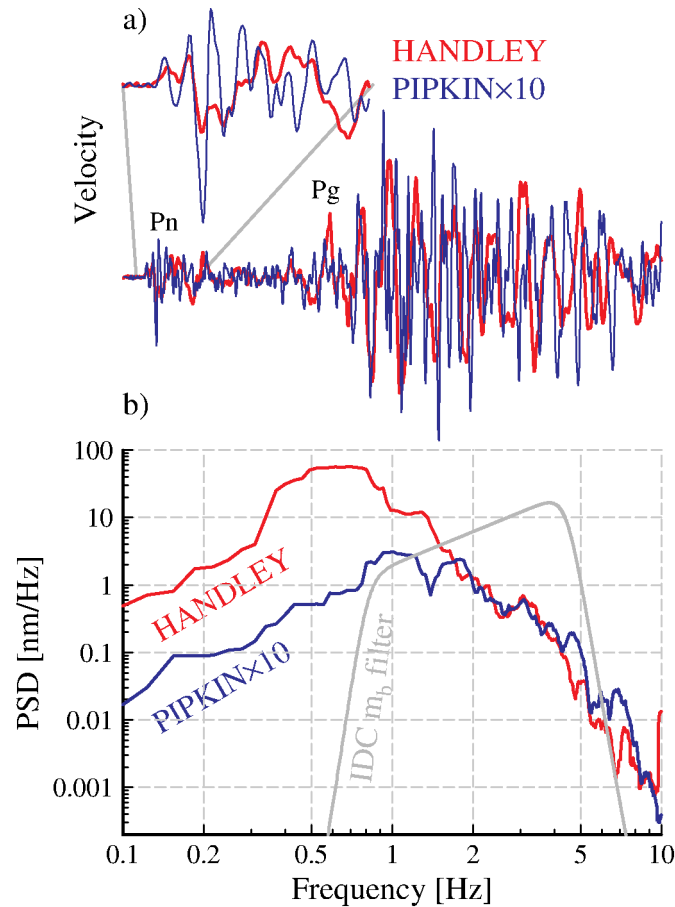


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